# Prospects for New Rare-Earth Mines Outside of China

Roderick G. Eggert

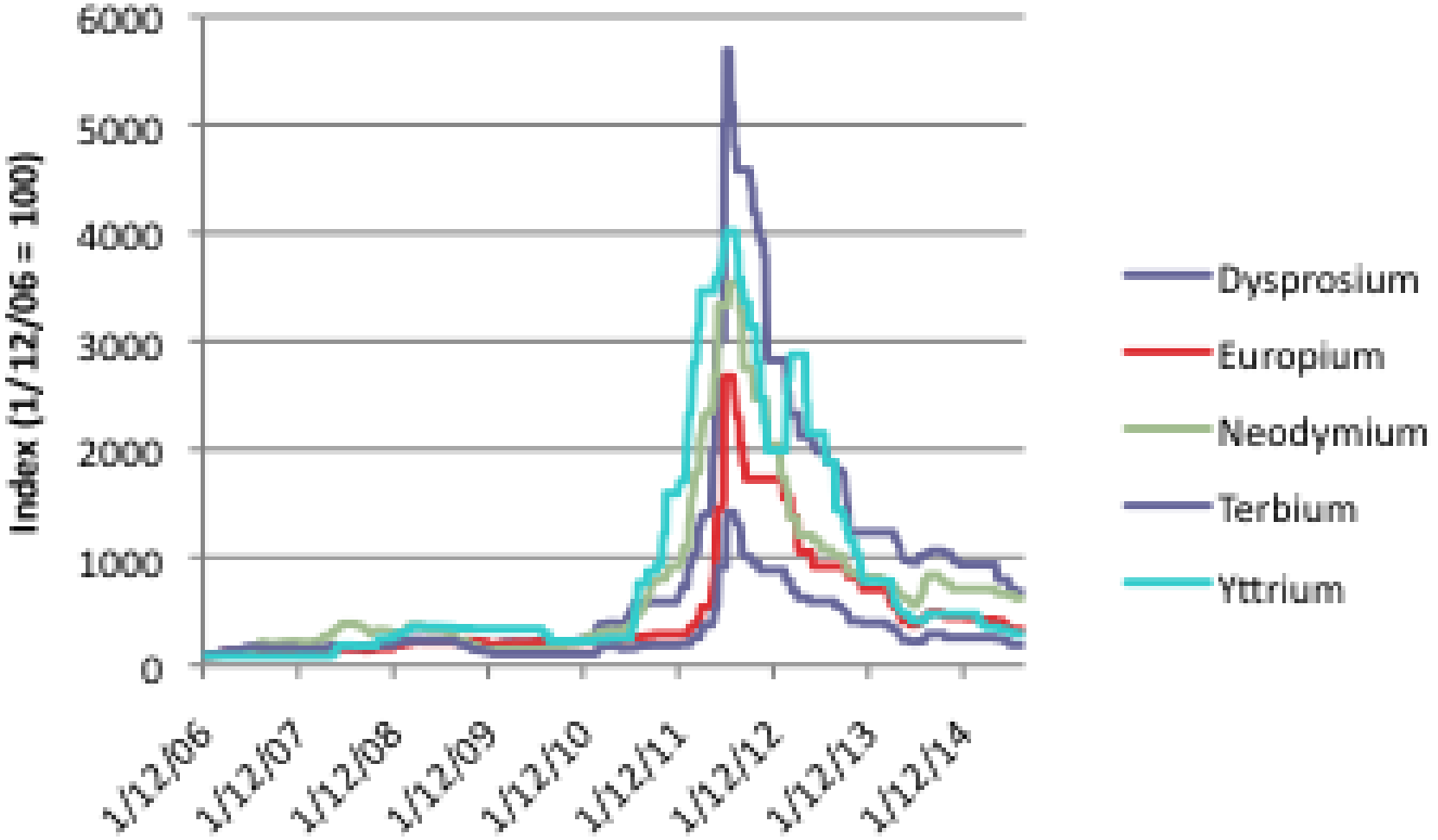
Professor, Colorado School of Mines
Deputy Director, Critical Materials Institute
reggert@mines.edu

All-CMI Plenary Session
Ames, September 9, 2014

# Starting points

- What are the prospects for mine production outside of China?
- Mountain Pass, California; Mount Weld, Australia
  - In production, but with start-up challenges
- 300-400 reported exploration properties two years ago
  - What has become of them?
- Framework
  - Market environment
  - Project-specific factors

# Indexed rare-earth oxide prices, FOB China
## (6 January 2006 – 4 September 2014)




Source: metal-pages.com

# Chinese export prices for rare-earth oxides, 2006 - 2014 (US$/kg, rounded)

| Oxide | January 2006 | January 2010 | Peak 2011 | 4 Sept 2014 |
|---|---|---|---|---|
| Lanthanum | 19 | 6 | 172 | 5 |
| Cerium | 15 | 4 | 158 | 5 |
| Praseodymium | 10 | 22 | 249 | 120 |
| Neodymium | 10 | 23 | 338 | 60 |
| Samarium | 3 | 5 | 129 | 6 |
| Europium | 220 | 480 | 5870 | 725 |
| Gadolinium | NA | 7 | 203 | 47 |
| Terbium | 320 | 350 | 4510 | 615 |
| Dysprosium | 50 | 117 | 2840 | 340 |
| Yttrium | 5 | 10 | 183 | 13 |

Source: metal-pages.com

# Chinese export prices for rare-earth oxides, 2006 - 2014 (US$/kg, rounded)

| Oxide | January 2006 | January 2010 | Peak 2011 | 4 Sept 2014 |
|---|---|---|---|---|
| Lanthanum | 19 | 6 | 172 | 5 |
| Cerium | 15 | 4 | 158 | 5 |
| Praseodymium | 10 | 22 | 249 | 120 |
| Neodymium | 10 | 23 | 338 | 60 |
| Samarium | 3 | 5 | 129 | 6 |
| Europium | 220 | 480 | 5870 | 725 |
| Gadolinium | NA | 7 | 203 | 47 |
| Terbium | 320 | 350 | 4510 | 615 |
| Dysprosium | 50 | 117 | 2840 | 340 |
| Yttrium | 5 | 10 | 183 | 13 |

Source: metal-pages.com

# Chinese export prices for rare-earth oxides, 2006 - 2014 (US$/kg, rounded)

| Oxide | January 2006 | January 2010 | Peak 2011 | 4 Sept 2014 |
|---|---|---|---|---|
| Lanthanum | 19 | 6 | 172 | 5 |
| Cerium | 15 | 4 | 158 | 5 |
| Praseodymium | 10 | 22 | 249 | 120 |
| Neodymium | 10 | 23 | 338 | 60 |
| Samarium | 3 | 5 | 129 | 6 |
| Europium | 220 | 480 | 5870 | 725 |
| Gadolinium | NA | 7 | 203 | 47 |
| Terbium | 320 | 350 | 4510 | 615 |
| Dysprosium | 50 | 117 | 2840 | 340 |
| Yttrium | 5 | 10 | 183 | 13 |

Source: metal-pages.com

# Chinese export prices for rare-earth oxides, 2006 - 2014 (US$/kg, rounded)

| Oxide | January 2006 | January 2010 | Peak 2011 | 4 Sept 2014 |
|---|---|---|---|---|
| Lanthanum | 19 | 6 | 172 | 5 |
| Cerium | 15 | 4 | 158 | 5 |
| Praseodymium | 10 | 22 | 249 | 120 |
| Neodymium | 10 | 23 | 338 | 60 |
| Samarium | 3 | 5 | 129 | 6 |
| Europium | 220 | 480 | 5870 | 725 |
| Gadolinium | NA | 7 | 203 | 47 |
| Terbium | 320 | 350 | 4510 | 615 |
| Dysprosium | 50 | 117 | 2840 | 340 |
| Yttrium | 5 | 10 | 183 | 13 |

Source: metal-pages.com

# Market environment

- Prices
- Demand
  - Little if any growth since ~2011
  - Immediate and lagged 'demand destruction'
  - 'wait and see'
  - Magnets perhaps biggest potential growth market

# Manufacturing demand for rare earths (000 metric tonnes REO, ± 20%)

| | World | China | ROW | Magnets | Phosphors |
|---|---|---|---|---|---|
| 2008 | 124 | 73 | 51 | 26 | 9 |
| 2009 | 86 | 60 | 26 | 22 | 6 |
| 2010 | 123 | 74 | 49 | 25 | 9 |
| 2011 | 110 | 75 | 35 | 23 | 9 |
| 2012 | 117 | 78 | 40 | 25 | 9 |
| 2013 | 115 | 78 | 38 | 29 | 7 |
| 2014f | 124 | 81 | 42 | | |
| 2015f | 133 | 84 | 49 | | |
| 2017f | 153 | 93 | 60 | 42 | 7 |
| 2020f | 190 | 115 | 75 | | |

Source: Dudley Kingsnorth f = forecast

# Manufacturing demand for rare earths (000 metric tonnes REO, ± 20%)

| | World | China | ROW | Magnets | Phosphors |
|---|---|---|---|---|---|
| 2008 | 124 | 73 | 51 | 26 | 9 |
| 2009 | 86 | 60 | 26 | 22 | 6 |
| 2010 | 123 | 74 | 49 | 25 | 9 |
| 2011 | 110 | 75 | 35 | 23 | 9 |
| 2012 | 117 | 78 | 40 | 25 | 9 |
| 2013 | 115 | 78 | 38 | 29 | 7 |
| 2014f | 124 | 81 | 42 | | |
| 2015f | 133 | 84 | 49 | | |
| 2017f | 153 | 93 | 60 | 42 | 7 |
| 2020f | 190 | 115 | 75 | | |

Source: Dudley Kingsnorth f = forecast

# Manufacturing demand for rare earths (000 metric tonnes REO, ± 20%)

| | World | China | ROW | Magnets | Phosphors |
|---|---|---|---|---|---|
| 2008 | 124 | 73 | 51 | 26 | 9 |
| 2009 | 86 | 60 | 26 | 22 | 6 |
| 2010 | 123 | 74 | 49 | 25 | 9 |
| 2011 | 110 | 75 | 35 | 23 | 9 |
| 2012 | 117 | 78 | 40 | 25 | 9 |
| 2013 | 115 | 78 | 38 | 29 | 7 |
| 2014f | 124 | 81 | 42 | | |
| 2015f | 133 | 84 | 49 | | |
| 2017f | 153 | 93 | 60 | 42 | 7 |
| 2020f | 190 | 115 | 75 | | |

Source: Dudley Kingsnorth f = forecast

# Manufacturing demand for rare earths (000 metric tonnes REO, ± 20%)

| | World | China | ROW | Magnets | Phosphors |
|---|---|---|---|---|---|
| 2008 | 124 | 73 | 51 | 26 | 9 |
| 2009 | 86 | 60 | 26 | 22 | 6 |
| 2010 | 123 | 74 | 49 | 25 | 9 |
| 2011 | 110 | 75 | 35 | 23 | 9 |
| 2012 | 117 | 78 | 40 | 25 | 9 |
| 2013 | 115 | 78 | 38 | 29 | 7 |
| 2014f | 124 | 81 | 42 | | |
| 2015f | 133 | 84 | 49 | | |
| 2017f | 153 | 93 | 60 | 42 | 7 |
| 2020f | 190 | 115 | 75 | | |

Source: Dudley Kingsnorth f = forecast

# Manufacturing demand for rare earths (000 metric tonnes REO, ± 20%)

| | World | China | ROW | Magnets | Phosphors |
|---|---|---|---|---|---|
| 2008 | 124 | 73 | 51 | 26 | 9 |
| 2009 | 86 | 60 | 26 | 22 | 6 |
| 2010 | 123 | 74 | 49 | 25 | 9 |
| 2011 | 110 | 75 | 35 | 23 | 9 |
| 2012 | 117 | 78 | 40 | 25 | 9 |
| 2013 | 115 | 78 | 38 | 29 | 7 |
| 2014f | 124 | 81 | 42 | | |
| 2015f | 133 | 84 | 49 | | |
| 2017f | 153 | 93 | 60 | 42 | 7 |
| 2020f | 190 | 115 | 75 | | |

Source: Dudley Kingsnorth f = forecast

# Manufacturing demand for rare earths (000 metric tonnes REO, ± 20%)

| | World | China | ROW | Magnets | Phosphors |
|---|---|---|---|---|---|
| 2008 | 124 | 73 | 51 | 26 | 9 |
| 2009 | 86 | 60 | 26 | 22 | 6 |
| 2010 | 123 | 74 | 49 | 25 | 9 |
| 2011 | 110 | 75 | 35 | 23 | 9 |
| 2012 | 117 | 78 | 40 | 25 | 9 |
| 2013 | 115 | 78 | 38 | 29 | 7 |
| 2014f | 124 | 81 | 42 | | |
| 2015f | 133 | 84 | 49 | | |
| 2017f | 153 | 93 | 60 | 42 | 7 |
| 2020f | 190 | 115 | 75 | | |

Source: Dudley Kingsnorth f = forecast

# Market environment

- Prices
- Demand
- Supply
  - Consolidation & vertical integration (upstream) in China
  - WTO aftermath: likely narrowing of price gap, stricter production quotas
  - New mine production in USA & Australia, but China still dominates supply chain
  - Room for perhaps 5-6 mines by 2020

# Market environment

- Prices
- Demand
- Supply
- Uncertainty dominates
  - 'chicken-and-egg' situation

# Project-specific discussion

- TMR Advanced Rare-Earth Project Index (www.techmetalsresearch.com)
- Adamas Intelligence (www.adamasintel.com)

- ~50 projects with compliant resource estimates or beyond

# TMR top 10: total REO (Mt)

- TANBREEZ, Greenland
- Niobec, Canada
- Kvanefjeld, Greenland
- Ashram Main, Canada
- Mrima Hill Main, Kenya
- Strange Lake Granite, Canada
- Montviel, Canada
- Serensen, Greenland
- Nechalacho Upper, Canada
- Mountain Pass, USA

Source: www.techmetalsresearch.com, update of July 21, 2014

# TMR top 10: total REO (wt%)

- Steenkampskral, South Africa
- Mount Weld CLD, Australia
- Mrima Hill High Grade, Kenya
- Mountain Pass, USA
- Wigu Hill Twiga, Tanzania
- Mount Weld Duncan, Australia
- Kangankunde, Malawi
- Araxá, Brazil
- Ngualla, Tanzania
- Mrima Hill Main, Kenya

Source: www.techmetalsresearch.com, update of July 21, 2014

# TMR top 10: in-situ total REO (US$/tMR)

- Steenkampskral, South Africa
- Mount Weld CLD, Australia
- Mrima Hill High Grade, Kenya
- Mount Weld Duncan, Australia
- Mountain Pass, USA
- Ngualla, Tanzania
- Mirma Hill Main, Kenya
- Araxá, Brazil
- Kangankunde, Malawi
- Wigu Hill Twiga, Tanzania

Source: www.techmetalsresearch.com, update of July 21, 2014

# TMR top 10: basket price (US$/recoverable kg REO)

- Browns Range, Australia
- Lofdal, Namibia
- Hastings, Australia
- Kutessay II, Kyrgyzstan
- Bokan, USA
- Norra Kärr, Sweden
- Strange Lake Enriched, Canada
- Nechalacho Basal, Canada
- Round Top, USA
- Olserum, Sweden

Source: www.techmetalsresearch.com, update of July 21, 2014

# Adamas top 10: exploration

- Browns Range, Australia
- Buckton South, Canada
- Clay-Howells, Canada
- Cummins Range, Australia
- Hoidas Lake (JV), Canada
- Kangankunde,Malawi
- Kutessay II, Kyrgyzstan
- La Paz, USA
- Lavergne-Springer, Canada
- Lofdal, Namibia

www.adamasintel.com, update of June 4, 2014

# Adamas top 10: development

- Aksu Diamas, Turkey
- Araxá, Brazil
- Ashram Main & MHREO, Canada
- Bear Lodge, USA
- Bokan Dotson Ridge, USA
- Buckton Main, Canada
- Charley Creek (JV), Australia
- DZP, Australia
- Eco Ridge, Canada
- Foxtrot, Canada

www.adamasintel.com, update of June 4, 2014

# Confused?

- Rankings are great fun, informative, valuable for identifying & understanding key success characteristics
- But inevitably incomplete – also must consider:
  - Mineralogy (process engineering, Th)
  - Location & infrastructure (partially captured by Adamas capital costs)
  - Co-production (partially captured in Adamas)
  - Political, social, regulatory considerations
  - The existence of a customer for specific products a project has demonstrated it can produce?

# Confused?

- Rankings are great fun, informative, valuable for identifying & understanding key success characteristics
- But inevitably incomplete
- *A key strategic dimension of the RE sector: 'differentiation' rather than 'cost leadership'*

# Broader inferences & final thoughts

- Mountain Pass (USA) and Mount Weld (Australia) will overcome their technical challenges & enjoy some degree of success
  - Important for other projects in the short term
- What of the other '400'?
  - Most are or will be 'back on the shelf' until the next boom
  - Most require demand growth, reversal of demand destruction
  - All are affected by what happens in China, Bayan Obo
  - Perhaps 5-6 will come into production by 2020

# What is under-appreciated?

- Lack of demand growth at present
- Continuing fragile supply chains
- Significant potential for increased primary production . . . that would be facilitated by:
  - Better basic geoscience
  - Enhanced process engineering

# Questions?

Contact information:
Roderick G. Eggert
Division of Economics and Business
Colorado School of Mines
Golden, Colorado USA 80401
Phone: +1 303 273 3981
E-mail: reggert@mines.edu
Websites: econbus.mines.edu, cmi.ameslab.gov

# TMR rare-earth list

- List includes
  - 57 resources (NI 43-101, JORC, SAMREC, etc.)
  - 51 properties
  - 49 companies
  - 16 countries
  - Last updated July 21, 2014

# Adamas Intelligence

- Evaluation & ranking of REE projects
- Exploration-stage rankings (27 projects)
  - Tonnes TREO (40%)
  - Tonnes CREO & relative abundance of CREOs (30%)
  - Hypothetical value of TREO (20%)
  - Relative abundance of (TREO – La/Ce) (10%)
  - 'Exploration' = compliant resource estimate only

# Adamas (continued)

- Development-stage rankings (25 projects)
  - Gross profit from REO and REO equivalent over life of mine (40%)
  - Tonnes of CREO recovered over life of mine (20%)
  - Capital expense payback period (15%)
  - (Revenues from non-REOs/total cost) + (revenues from REOs/total cost) (10%)
  - Tonnes per year of less-desirable REOs produced (7.5%)
  - Project capital cost per tonne of REO & REO equivalent produced per year (7.5%)